Satellite tracking of pink-footed shearwaters (*Puffinus creatopus*)

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Abstract

As part of a broader research program focusing on the ecology and conservation of the threatened seabird community of the Juan Fernández Islands, Chile, we studied the foraging ecology of breeding pink-footed shearwaters (*Puffinus creatopus*) during the early to mid-chick rearing period, using satellite transmitters to determine foraging locations and habitat use patterns. In addition, we utilized conventional diet sampling and stable isotope analyses to quantify diet and trophic level. Of 12 deployments on breeding shearwaters with chicks, we obtained tracking data for nine complete foraging trips. Shearwaters primarily traveled to the continental shelf and shelf break (6 of 9 trips) but also exploited pelagic waters (3 of 9 trips). Oceanographic conditions varied between these two trip types with regions used during shelf/shelf break foraging trips characterized by shallower water depths, colder sea surface temperatures and higher chlorophyll *a* concentrations. The shelf/shelf break region utilized by shearwaters in this study is the same region identified by Guicking et al. (2001) as a foraging zone hotspot for pink-footed shearwaters breeding on Isla Mocha, Chile and overlaps with the Chilean region that has the largest fishing industry. Actual overlap with fisheries and fishery types are currently unknown. Diet sample analyses indicate a diet dominated by fish (~90% by biomass and frequency of occurrence), with squid and salps comprising smaller fractions. Preliminary results of stable isotope analyses ($\delta^{15}N$ and $\delta^{13}C$) also suggest a fish-dominated diet for both adults and chicks. This study provides initial insights into pink-footed shearwater foraging ecology and habitat use patterns and may be used to assess potential interactions with commercial fisheries.

Introduction and objectives

For more than a decade, satellite transmitters have been used successfully to track seabirds in order to address questions related to habitat use, foraging ecology and conservation. This work has principally involved albatrosses and penguins (e.g. Garcia Borboroglu et al. 2002, Fernandez et al. 2001, Cherel et al. 2000, Stokes and Boersma 1999), although the advent of lighter transmitters now makes it

feasible to track smaller seabirds, including shearwaters and petrels (e.g. Hyrenbach et al. 2004, Guicking et al. 2001, Catard et al. 2000, Klomp and Schultz 2000). In this study, we used satellite tracking technology to quantify pink-footed shearwater foraging strategies and habitat use patterns and to assess how they relate to possible interactions with commercial fisheries.

The pink-footed shearwater is a poorly studied seabird species endemic to Chile. There are only three confirmed breeding locations for the species, two islands in the Juan Fernández Archipelago and Isla Mocha. Because of their restricted breeding distribution and suggestions that populations have been declining (Schlatter and Simeone 1999, Bourne et al. 1992, Schlatter 1984), pink-footed shearwaters are listed as Vulnerable by the International Union for the Conservation of Nature (Collar et al. 1994).

This study addressed the following three research objectives and subsidiary questions:

1. determine foraging locations and habitat use patterns of breeding adult pink-footed shearwaters during the early-mid chick rearing period using satellite tracking technology
    a. are pink-footed shearwaters traveling from the breeding colonies to the Humboldt Current/Chilean continental shelf or are they foraging pelagically, offshore of the current's influence?
    b. do pink-footed shearwater foraging locations overlap with areas in which commercial fisheries operate?
2. relate habitat use patterns (objective 1) to oceanographic conditions using remotely-sensed data
    a. is there a relationship between oceanographic parameters (i.e. sea surface temperature, chlorophyll *a* concentrations and bathymetry) and habitat use patterns in pink-footed shearwaters?
3. quantify diet composition and trophic level of pink-footed shearwaters using conventional diet sampling techniques and stable isotope analyses ($\delta^{15}N$ and $\delta^{13}C$) to quantify shearwater diet and trophic level.

Methods

Study site

We conducted the study on Isla Santa Clara, Juan Fernández Archipelago, Chile (33°43'S, 78°56'W) from 5 February through 6 March 2004.

Satellite tracking

We deployed six battery operated satellite platform transmitter terminals (PTTs) on 12 breeding adults from 11 active burrows (two tagged adults were a breeding pair) during the chick period. All tagged birds had a chick at the time of tag deployment. Tags were deployed between 8 and 28 February 2004. Tags, three each of Microwave Telemetry Pico PTT-100 and North Star PTT-20G, weighed 20 grams, not including attachment materials. We attached transmitters to 20-25 dorsal contour feathers, slightly above the base of the rectrices, using Tesa brand tape. We marked each tagged bird with two plastic Darvic leg bands. To minimize impacts to individual birds and to maximize our sample size, we attempted to recapture each bird and remove the PTT after a single foraging trip. We were unable to recapture one bird upon its initial return and, thus, have two foraging trips for that individual. Birds were weighed at the time of tag attachment and also when recaptured for tag removal to assess possible changes in body condition. We also collected morphometric measurements (wing chord length, tarsus length and culmen length) from recaptured birds.

We used ETOPO-5 bathymetry charts and weekly remotely-sensed sea surface temperature and chlorophyll *a* concentration data for Feb. 2004 from the NOAA Aqua Modis satellite (http://modis.gsfc.nasa.gov/).

Diet sampling

We opportunistically collected 10 spontaneous regurgitations from breeding adult shearwaters captured on the colony. These samples were preserved in 98% ethanol. We sorted samples into identifiable taxonomic groups (i.e. fish, squid, crustacean, other) and determined frequency of occurrence and percent composition by mass. Hard parts such as fish otoliths, vertebral columns and pieces of flesh

with attached skin and squid beaks were retained for further identification. Following these analyses, we removed small representative diet subsamples to be analyzed using stable isotope analyses (see below).

Stable isotope analyses (SIA) of trophic level

We used needle and syringe to collect blood samples from the brachial vein of breeding adult (n=11) and nestling (n=6) shearwaters. We stored all blood and diet (described above) SIA samples in 98% ethanol. These samples are currently being analyzed by Dr. Keith Hobson at the stable isotope facility of the Prairie and Northern Wildlife Research Centre in Saskatoon, Canada.

Results

Satellite tracking

The six transmitters were deployed 12 times, for a total of 13 foraging trips (one bird recorded two consecutive trips). Two tags were lost at sea and transmission failed for two other deployments, after 9.7 and 0.58 days of tracking, thus yielding data for partial foraging trips. We have tracking data for nine complete foraging trips, trip length data for 12 trips and trip destination information for 10 trips (Table 1).

Table 1. Duration of foraging trips and location parameters for breeding pink-footed shearwaters tracked by satellite telemetry, Isla Santa Clara, Chile.

Bird trip #[1]	Deployment date	Trip length (days)	# of locations used[2]	Maximum range (km)	Trip destination
1	8 Feb.	13.06	87	-	Chilean shelf
2	8 Feb.	6.98	43	428.19	deep water ENE of colony
3	9 Feb.	8.01	177	577.88	deep water W of colony
4	9 Feb.	8.26	77	687.45	Chilean shelf
5a	9 Feb.	8.95	100	644.49	Chilean shelf
5b	18 Feb.	9.12	68	627.61	Chilean shelf
6	9 Feb.	8.96	98	646.03	Chilean shelf
7	16 Feb.	-	8	-	-
8	17 Feb.	15.24	48	-	-
9	18 Feb.	5.29	60	626.17	Chilean shelf
10	18 Feb.	7.14	98	625.29	Chilean shelf
11	25 Feb.	8.88	115	443.41	deep water SW of colony
12	28 Feb.	6.77	0	-	-
Mean ± 1 SD		8.89 ± 2.74		589.61 ± 91.78	

[1] Trip 5 split into 5a and 5b because they were two successive trips by same bird
[2] Location classes 3 through A used in analyses (B and 0 classes excluded)

Trip duration ranged from 5.3-15.2 days, with a mean trip length of 8.9 ± 2.7 days. Tracked birds headed primarily in an easterly direction (8 of 10 tracks) on their foraging trips with seven traveling to the

Chilean continental shelf, spending considerable time in shelf waters (<200 m depth) (Fig. 1). One bird, although heading east, remained over deep water throughout its foraging trip (Fig. 2). Two birds headed west from the colony, remaining over deep, pelagic water during the entire trip; one traveled to the WSW of Isla Alejandro Selkirk, the westernmost island in the archipelago, and the other to the SW of Selkirk. Maximum linear distances from the island for all complete trips ranged from 428 to 687 kilometers (mean = 590 ± 92 km).

Preliminary analyses indicate that the shelf/shelf break region visited in the six shelf/shelf break foraging trips (Fig. 1) was characterized by shallower mean water depth, with 26% of the trip spent in waters <1000m in depth versus 4% for the three pelagic trips. The shelf/shelf break region also had higher mean chlorophyll *a* concentrations and lower mean sea surface temperatures relative to the three pelagic trips. Figure 4 illustrates representative sea surface temperatures and chlorophyll *a* concentrations during the study period.

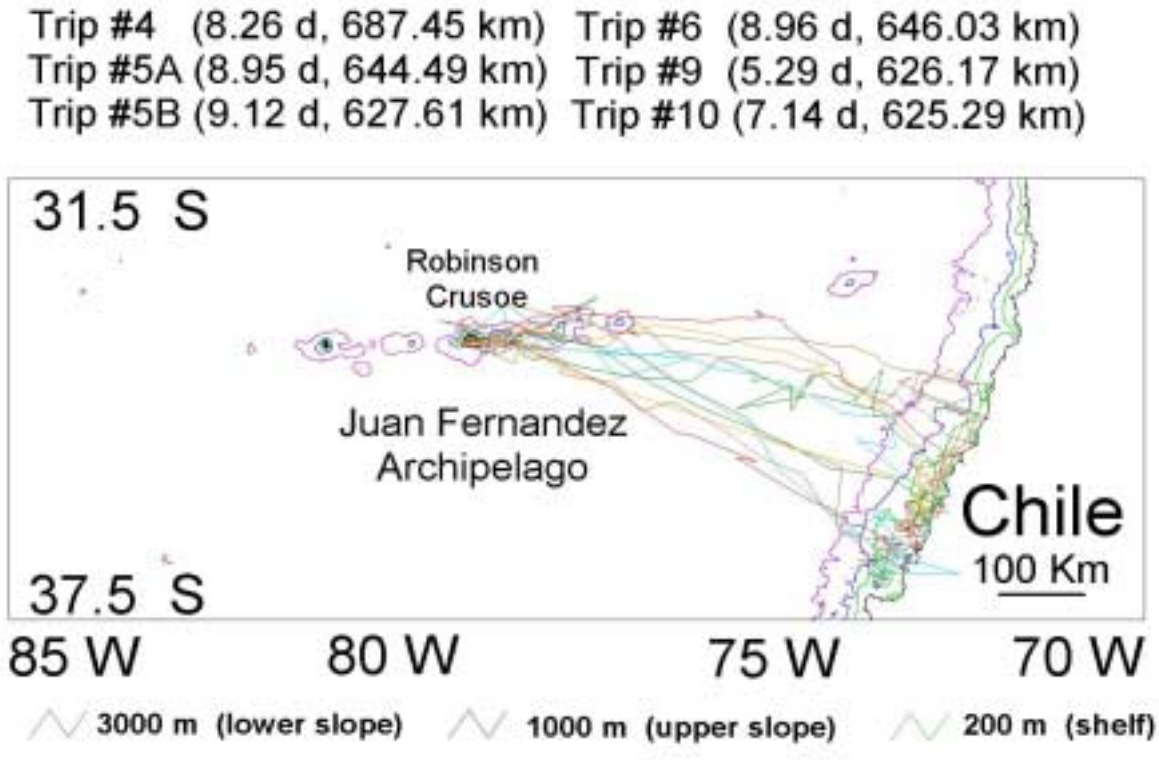

Figure 1. Complete foraging trip tracks of five pink-footed shearwaters (two trips by one bird) that traveled to the Chilean shelf. Trip numbers correspond to numbers in Table 1.

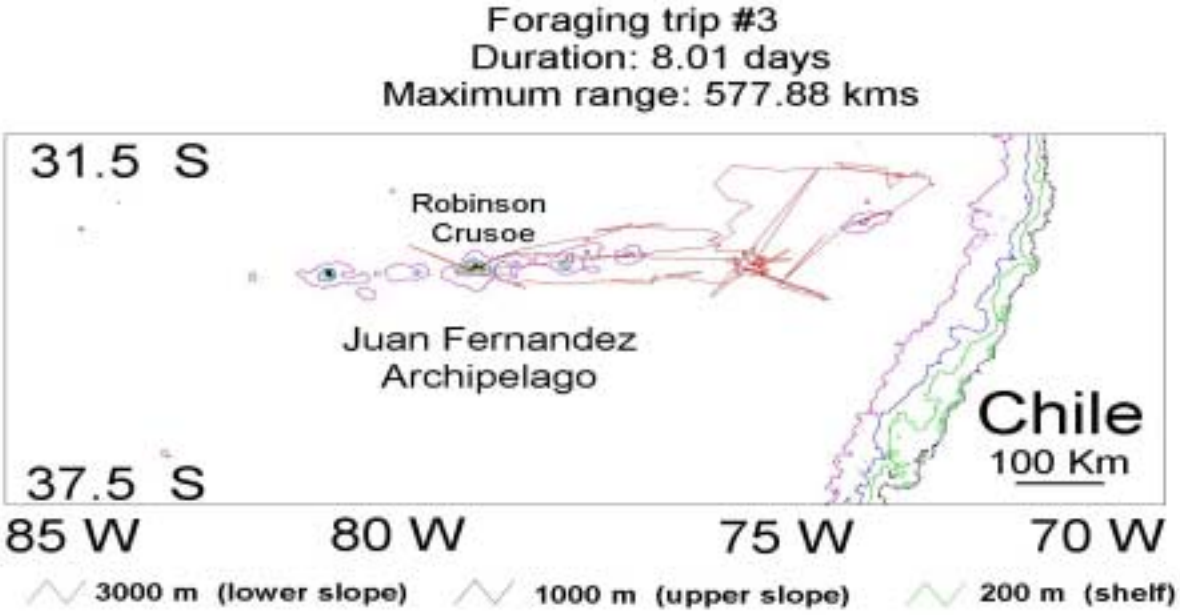

Figure 2. Complete foraging trip track of one pink-footed shearwater that traveled to the east, remaining over deep water. Trip number corresponds to number in Table 1.

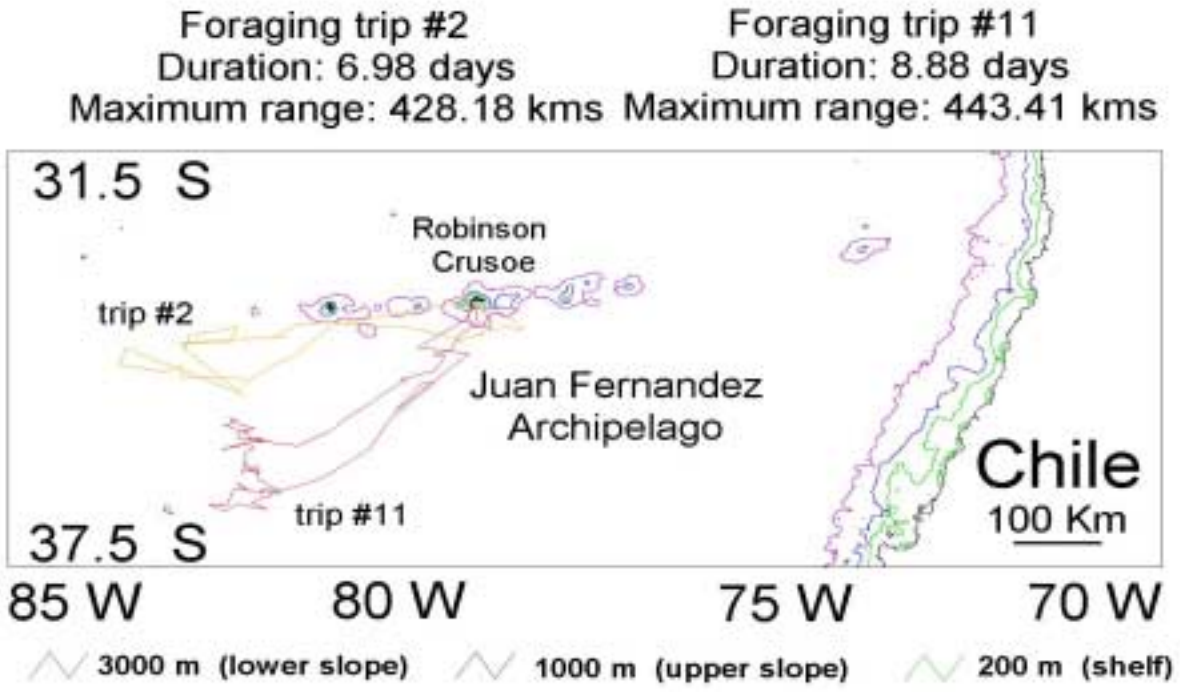

Figure 3. Complete foraging trip tracks of two pink-footed shearwaters that traveled to the west, remaining over deep water. Trip number corresponds to number in Table 1.

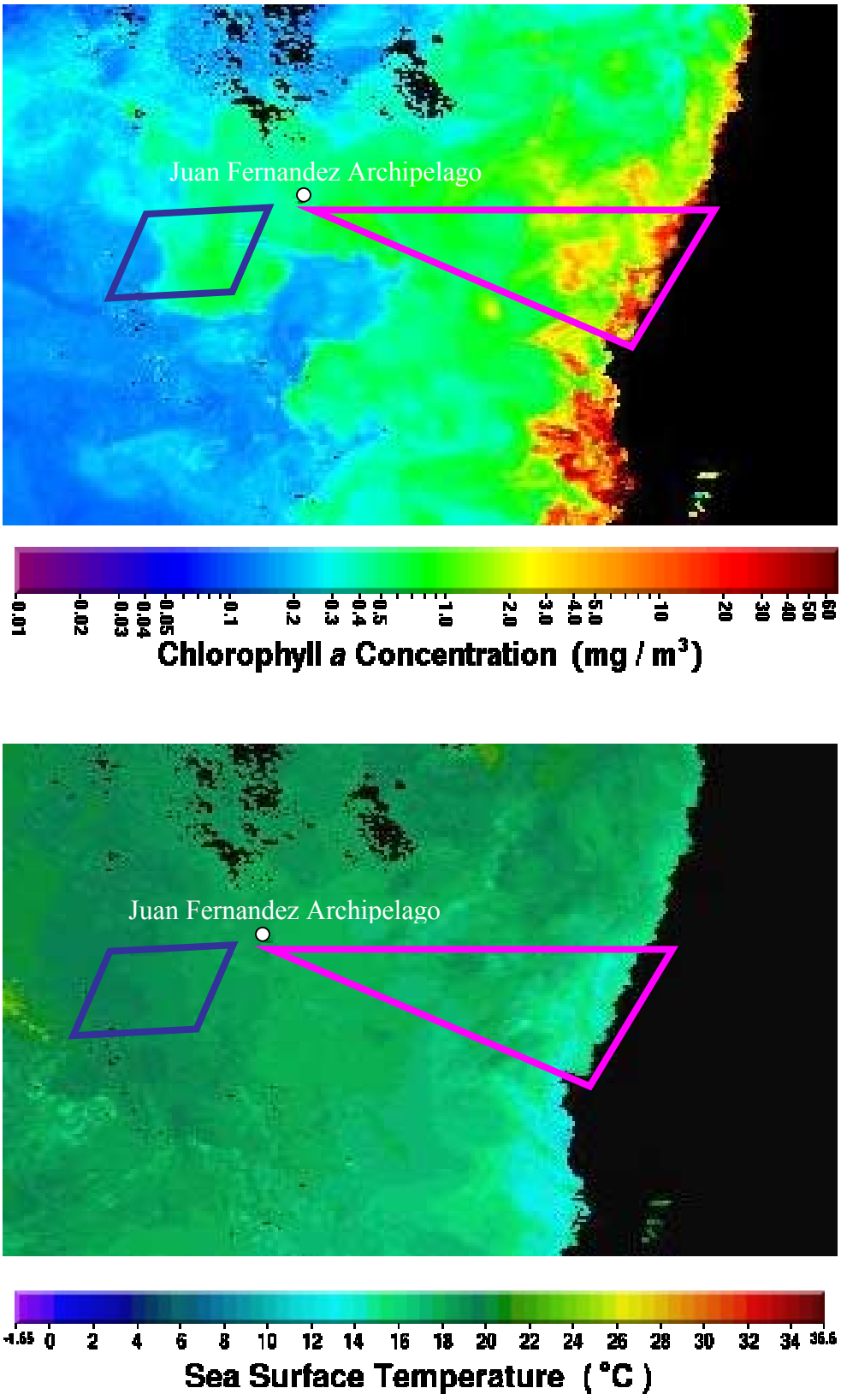

Figure 4. Chlorophyll *a* concentrations (top figure) and sea surface temperatures (bottom figure) for week of 18-25 Feb. 2004. Pink triangles represent region utilized on six foraging trips to the shelf/shelf break. Purple parallelogram represents region utilized on two foraging trips to pelagic waters. Black is continental Chile.

Diet sampling

Fish was the dominant prey type in shearwater diet samples, in terms of both frequency of occurrence and biomass. Remains of fish, found in all but one of the 10 samples collected, comprised nearly 90% of the diet by mass. Because of the advanced state of digestion of most of the fish and the lack of fish heads in the samples, none could be identified. No otoliths were found in the samples. Potentially identifiable fish hard parts have been sent to a Chilean fish biologist, Dr. German Pequeño of the Universidad Austral de Chile, for identification. Three diet samples contained squid, two of which were largely intact, missing only the mantle. Squid beaks have been sent to Dr. Michael Imber of the New Zealand Dept. of Conservation, an expert in Pacific Ocean squid beaks, for identification. No crustaceans were found in any of the samples. Two of the samples contained items tentatively identified as pieces of salp. These samples have been retained for definitive identification by an expert. Two samples contained small pieces of plastic.

Stable isotope analyses

Samples collected during the 2004 field season are currently being analyzed by Dr. Keith Hobson, Canadian Wildlife Service. Thus, at present we do not have results from this component of the study. However, samples from the 2002 and 2003 field seasons have been analyzed, and we present these data in conjunction with comparable data from other seabirds breeding in the Juan Fernández Archipelago for illustrative purposes (Figure 5). Statistical analyses will only be presented for shearwater data.

Adult shearwater $\delta^{15}N$ values did not differ between years ($t_{19} = 1.18$, $p = 0.25$). Adult and chick $\delta^{15}N$ values (for the 2002 and 2003 seasons and 2002 season, respectively) differed (ANOVA: $F_{2, 29} = 6.16$, $p < 0.01$), with Tukey HSD post-hoc tests indicating that chicks (2002 season) had higher $\delta^{15}N$ values than 2002 adults ($p < 0.01$) but not 2003 adults ($p = 0.09$). Adult shearwater $\delta^{13}C$ values did not differ between years ($t_{19} = 1.88$, $p = 0.08$) or from chicks (ANOVA: $F_{2, 29} = 2.79$, $p = 0.08$; Tukey HSD $p > 0.05$).

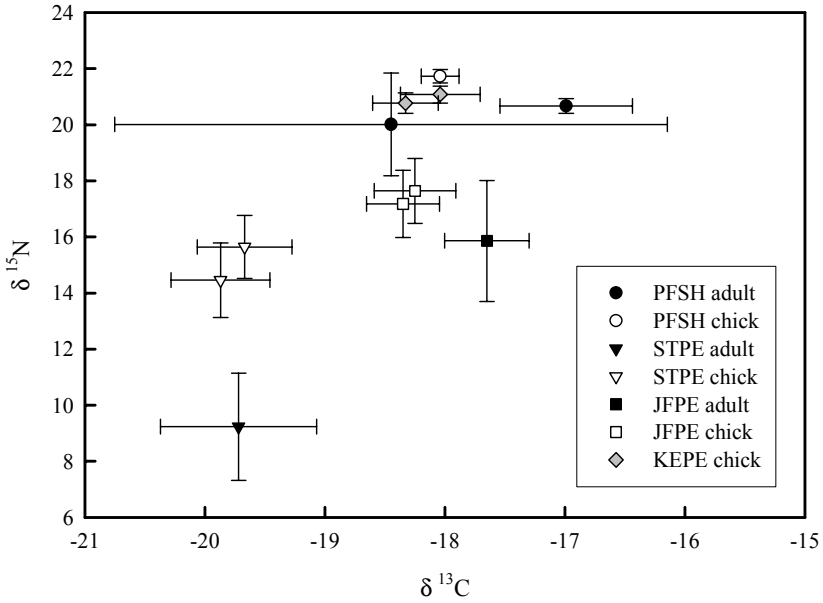

Figure 5. Mean $\delta^{15}N$ and $\delta^{13}C$ values for seabirds during the 2002 and 2003 breeding seasons (error bars = 1 S.D.) Petrel abbreviations: PFSH = pink-footed shearwater; STPE = Stejneger's petrel (*Pterodroma longirostris*); JFPE = Juan Fernández petrel (*Pterodroma externa*); KEPE = Kermadec petrel (*Pterodroma neglecta*).

DISCUSSION

Satellite tracking

Pink-footed shearwaters breeding on Isla Santa Clara traveled primarily east to the Chilean continental shelf in the Talcahuano region on foraging trips during the early-mid chick rearing period in 2004. This area, between 34-37°S, was also used by breeding shearwaters tracked during the 2003 breeding season but was not used extensively by three birds tracked during 2002 (Hodum and Wainstein 2002, 2003). The region is characterized by higher average chlorophyll *a* concentrations, a proxy for phytoplankton biomass, and lower sea surface temperatures than waters beyond the shelf break. Thus, it appears that the birds are selecting colder inshore waters with high primary productivity in which to forage. Our results support previous findings that pink-footed shearwaters show strong preference for traveling and feeding near the mainland coast (del Hoyo et al. 1992 and Guicking et al. 2001). In addition, Guicking et al. (2001) concluded that a major foraging zone for pink-footed shearwaters breeding on Isla Mocha occurred 250-300 km north of the island over the shelf (near Talcahuano), the same region to which the Santa Clara birds traveled in our study.

The shelf area to which the majority of the birds traveled falls partially within the Eighth Region of Chile (36-38.5°S) which is the region with the largest fishing industry in Chile (SERNAP 1998). Thus, there is potential overlap with commercial fisheries in what appears to be an important shearwater foraging region. That said, overlap does not imply interaction as type of fishery and shearwater foraging behavior both contribute to the likelihood of actual interactions. Our attempts at obtaining the fisheries location data from SERNAPESCA, the Servicio Nacional de Pesca, in Chile have thus far been unsuccessful. However, we have recently been invited to submit a formal petition to the Director of SERNAPESCA requesting access to the relevant fisheries data. If given access, we will be able to obtain information on types and locations of fisheries operating in the region in which shearwaters forage, thereby allowing us to assess whether or not spatial overlap exists between the fisheries and shearwater foraging areas.

Diet sampling

Very limited diet information for pink-footed shearwaters exists in the published literature. Murphy (1936) and Brown et al. (1978) reported that the diet consisted primarily of fish captured by shallow surface diving and surface seizing. Goodall et al. (1957) stated that sardines (*Strangomera bentincki*) and anchovies (*Engraulis ringens*) comprised the main prey species, findings supported by work by Guicking et al. (2001) in the Isla Mocha region. Squid have also been reported as dietary items (del Hoyo et al. 1992). Our results of a fish-dominated diet broadly agree with these earlier, largely anecdotal observations as well as with pilot diet work that we conducted during the 2002 and 2003 breeding seasons. Fish occurred in all 10 samples from these two seasons and comprised 100% of the diet by mass. Unlike our 2004 findings of squid in 20% of the samples, no squid were found in the 2002 and 2003 samples. The only non-fish item found was a single unidentified amphipod. Thus, the diet across all three seasons, albeit with limited sample sizes, was broadly similar with fish as the dominant prey item, comprising $\geq$89% of diet by mass and occurring in $\geq$90% of samples.

Stable isotope analyses

Results from 2002 and 2003 indicate similar relative trophic positions for both adult and nestling shearwaters. As expected for a seabird that provisions both itself and its chick with prey captured pelagically, stable-carbon ratios did not vary between adults and chicks. In marine systems, the $\delta^{15}N$ value provides greater insight into trophic dynamics because of its predictable stepwise trophic enrichment. With the preliminary results presented here, $\delta^{15}N$ values did not differ consistently between adults and chicks. This suggests that adults may provision their chicks with the same prey items that they consume for themselves. However, trophic overlap does not necessarily indicate shared prey types, and the small but significant difference in $\delta^{15}N$ values between adults and chicks in 2002 might indicate prey differences. Actual isotopic values for prey items (currently being analyzed), in addition to the 2004 shearwater SIA values, will enable us to better assess this issue.

In the broader context of seabird community trophic dynamics in the archipelago, pink-footed shearwaters occupy a significantly higher trophic level than both Juan Fernández and Stejneger's petrels and the same level as Kermadec petrels (Figure 5). These results suggest that both pink-footed shearwaters and Kermadec petrels feed primarily on fish while Stejneger's and Juan Fernández petrels consume higher proportions of squid.

Stable isotope data can also prove useful in long-term monitoring programs as they provide a standardized way of assessing diet between years and species. With the 2004 SIA samples, we now have a three-year data set for pink-footed shearwaters as well as for three other seabird species breeding in the archipelago. Coupled with breeding success parameters, we can use SIA data as a metric of conditions in the marine environment and how changing conditions may impact seabird reproductive success.

By combining satellite tracking, dietary analyses, and remote sensing data we are beginning to gain a better understanding of pink-footed shearwater foraging strategies and habitat use patterns. If we can obtain regional fisheries data from SERNAPESCA, we will be able to extend this information to assess potential interactions with commercial fisheries and how such interactions may impact this threatened species.

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